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External benefits of waste-to-energy in Korea: A choice experiment study

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ABSTRACT

The Korean government has planned to expand a variety of waste-to-energy (WtE) facilities in order to reduce waste disposal, decrease the crude oil imports, and mitigate greenhouse gases (GHGs) emissions. One response to this concern is to measure the external benefits of WtE. To this end, this study attempts to apply a choice experiment (CE) to four attributes or types of benefits such as the improvement of energy security, reduction of GHG emissions, job creation, and extension of landfill life expectancy. A survey of 500 households was undertaken in Seoul, Korea. The trade-offs between price and the four attributes for selecting a preferred alternative are considered in the CE survey and a marginal willingness to pay (MWTP) estimate for each attribute is derived. A nested logit (NL) model is employed in this study, rather than a multi-nomial logit (MNL) model since two specification tests indicate that the NL model outperforms the MNL model. The estimation results for the NL model show that the MWTPs for a 1% increase in energy security, a 1% reduction in GHG emissions, the creation of 10,000 new jobs, and the doubling of landfill life expectancy as a result of expanding WtE facilities is estimated to be KRW 437 (USD 4.5), 1763 (1.5), 598 (0.5), and 89 (0.1) per household per month, respectively. The findings can provide policy-makers with useful information for evaluating and planning WtE policies and projects.

Contents

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1. Introduction

After the Industrial Revolution the emission of global greenhouse gases (GHGs) such as carbon dioxide (CO_2) and methane sharply increased, and the average temperature and sea levels of the Earth continuously increased over the last 100 years. Glaciers have shrunk, ice is breaking up earlier, plant and animal ranges have shifted, and trees are flowering sooner. Regional climate change could alter forests, crop yields and water supplies, and threaten human health and many types of ecosystems. Thus, the environmental and social impacts of energy development have become an increasingly important topic of public debate in developing countries as well as in developed countries.

According to BP [1], in the prevailing conditions of increasing scrutiny into the environmental implications of the development process, Korea has received particular attention as the country's growth rate in CO_2 emissions is now the highest among the OECD countries (annual average of 7.3% for 1980–2012) and the amount of CO_2 emissions was 763.7 million tons in 2012, ranked seventh in the world. There is now general agreement that the most pressing need is to incorporate global warming concerns proactively into policy-making rather than simply reacting to the problems after they occur. This is because Korea will need to address the global warming problem as part of the international discussions that are now under way and because any international agreements reached will surely have repercussions in Korea.

Policy-makers are currently addressing the potential effectiveness of regulations and other measures for reducing GHG emissions to avoid future climate change impacts and abide by international agreements. One such measure is to develop waste-to-energy (WtE) facilities. With the urgent need to develop and distribute alternative forms of energy in the case of the depletion of fossil fuels and global warming, waste products are now considered a new energy resource and are employed as such. In WtE, waste includes wood and organic wastes such as food waste, livestock manure, and sewage sludge. In this regard, WtE belongs to biomass which is defined as a biological material derived from living or recently living organisms. This study focuses on WtE among various types of biomass. As of 2011, the ratio of WtE consumption to primary energy consumption amounted to just 1.89% in Korea. However, the Korean Ministry of Environment has planned to expand the ratio of WtE to 5% by 2020.

WtE has a number of advantages for Korea over other energy sources. First, it is quite a cost-effective source of energy among several new and renewable energies. Korea is the world's tenth largest energy consumer and imports 97% of its energy. Thus, it is essential to reduce the country's energy dependency by producing and widely distributing new and renewable energies that can replace fossil fuels such as oil and coal. The cost of WtE is approximately 10% of that of solar energy and 66% of that of wind energy.

Second, WtE can mitigate the generation of methane gas and thus effectively cope with climate change, considering that methane produces a heat-trapping effect in the atmosphere that is twenty one times stronger than that of CO_2. Recently, developed countries have been striving to reduce greenhouse effects by using refuse-derived fuel (RDF) made from combustible solid wastes to produce energy. In particular, the EU has set the goal of reducing CO_2 emissions by 320 million tons through the WtE program by 2010 and has implemented measures to do so.

Third, WtE can prevent the negative impacts of waste dumping in the oceans on the marine environment and ecosystem. As of the end of 2007, 53.8% of food wastewater which is generated in the process of food waste reuse, 68.5% of sewage sludge, and 4.1% of livestock manure have been disposed of through the ocean dumping method that adversely affects the marine environment and ecosystem in Korea. However, WtE can remove the necessity of ocean dumping of wastes.

Finally, WtE can make the development of landfill and/or incineration unnecessary. A number of problems arise from landfill sites, including security and foul odors. Incineration has the attendant problem of the enormous costs of dealing with CO_2 and other sources of air pollution. In contrast, biogas technology from organic waste, for example, instead of pursuing landfill or incineration methods, provides an opportunity to produce new and renewable energy and reduce GHG emissions in an effective manner.

Recently, there has been a growing call for the transition of waste management systems to establish sustainable development and a zero-waste society. With regard to this, WtE technology has the potential to be an efficient policy tool in resolving challenges involving the environmental, economic and greenhouse effects that we face today. Thus, most developed countries have actively pursued WtE technology development. Moreover, many efforts have been made to measure the benefits of WtE policies or projects [2–5]. This paper aims to add evidence from Korea to the current literature by estimating the willingness to pay (WTP) for WtE applying non-market valuation methods. Monetary valuations make it possible to evaluate various hypothetical policies that involve attributes of external benefits from WtE and their levels.

The purpose of this study is, therefore, to measure the external benefits of WtE using the specific case study of Korea. To this end, the study applies a choice experiment (CE) with four attributes or types of benefits, such as improvements in energy security, the reduction of GHG emissions, job creation, and the extension of landfill life expectancy. The remainder of this paper is organized as follows: Section 2 explains WtE in Korea and provides a literature review. Section 3 reviews the CE and its methodological issues. Section 4 presents statistical models to derive the WTP. Section 5 discusses the results. Concluding remarks are made in the final section.

2. WtE in Korea and review of the literature

2.1. WtE in Korea

As shown in Fig. 1, the total amount of new and renewable energy generated in 2011 was 7.58 million tons of oil equivalent (TOE), of which waste energy including waste gas accounted for about 5.12 million TOE [6]. The amount of renewable energy from waste excluding waste gas was 2.46 million TOE, accounting for just 1.89% of primary energy and 67.54% of new and renewable energy. This amount comes primarily from collecting residual heat generated from municipal waste incinerators or collecting waste landfill gas.

The share of WtE is quite low as the government has pursued a waste management policy based predominantly on recycling. According to the Korean Ministry of Environment (KMOE), government subsidies were only provided for waste recycling, incineration and landfill facilities, with almost none for WtE technology development. This is because the policy focused on the sanitary disposal of waste.

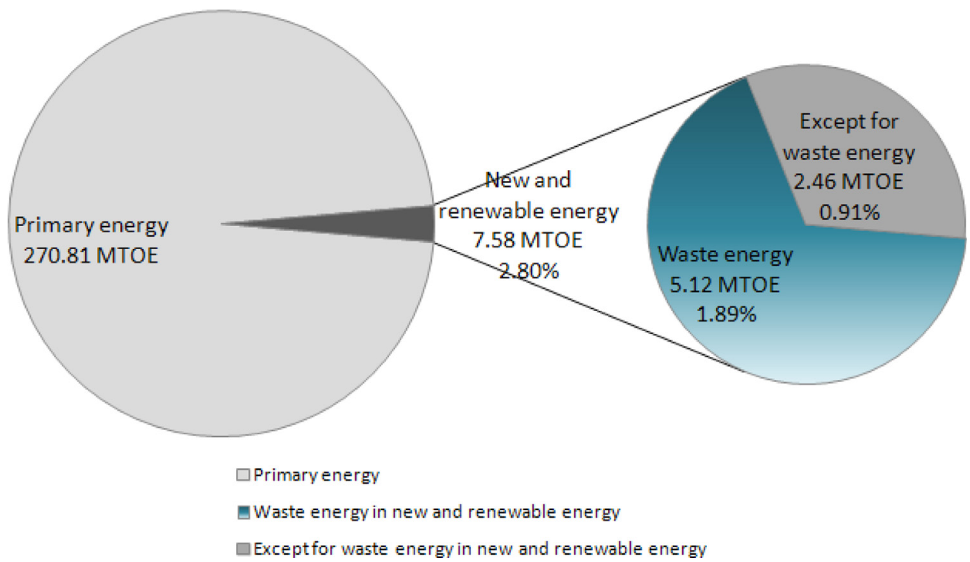


Fig. 1. Current status of new and renewable energy in Korea in 2011.
Source: Statistics Korea (available at 〈http://www.kostat.go.kr〉).

Moreover, the Korean Ministry of Trade, Industry and Energy, which is in charge of the development and distribution of renewable energy, offered financial support mostly to the solar, wind, small hydraulic power, and geothermal energy fields, and thus WtE received little policy assistance and few government subsidies. From the perspective of Korea's WtE technology development, RDF manufacturing technology in relation to combustible wastes is in practical use. However, the biogasification technology of organic waste is still considered to have a long way to go compared to that of advanced countries.

In order to increase the share of WtE in primary energy, Korea needs to expand the manufacturing of RDF, employing combustible solid wastes and exclusive power generation, electricity generation and purification projects using the biogasification of organic waste as advanced countries do. Therefore, the KMOE has provided national subsidies for the establishment of WtE facilities. As a result of its efforts to expand power generation facilities from waste, it completed the construction work of an RDF-producing facility (200 t of RDF per year) in a landfill site for the Metropolitan area (Seoul City – the capital of Korea; Incheon City; and Gyeonggi Province).

Moreover, WtE facilities in 19 regions are under construction or in the planning stage. Currently, there is a dispute between Incheon and Seoul about extending the life of the Metropolitan landfill. This facility is supposed to cease operation by the end of 2016. Seoul City is making a request for an extension of the deadline to 2044. However, Incheon City is asking Seoul City to keep its promise to use the landfill only until 2016. Seoul City, Gyeonggi Province, and the stakeholders are attempting to find a solution to the issue of the disposal of their waste.

The KMOE is promoting the systematic improvement and amendment of the relevant law in various ways with the intention of facilitating WtE policy. First, to cope with the imminent ban on the ocean dumping of organic waste which started in 2012, the KMOE is striving to expand the provisions regarding the use and method of waste utilization in the Waste Control Act to allow coal power plants to use sewage sludge as fuel. Second, the KMOE promulgated a law on permission for the manufacture and use of fluffy-type RDF for the purpose of its promotion. Third, the KMOE formed and is operating a consulting council with cement and paper manufacturing firms and other relevant businesses to expand the use of RDF. Finally, along with these measures, the KMOE plans to promote the revision of the relevant laws further to induce energy utilization of waste reclamation.

The KMOE is also implementing WtE research and development (R&D) programs. According to the MOE, it appears that the level of Korea's WtE technology is about 60% of that of developed countries and thus its fundamental technology and commercialization are limited. In order to raise the domestic technological level in WtE development to the 90–95% level represented by advanced countries by 2020 and nurture world-class state-of-the-art technology to lead the global market, the KMOE is conducting WtE R&D programs that consist of three steps: first, the practical study and commercialization of the obtained technology; second, developing technologies to secure new growth engines; and third, finding and developing state-of-the-art technology to lead the global market.

2.2. Literature review

A summary of previous studies dealing with the economic benefits of biomass energies is reported in Table 1. There have been studies on the valuation of diverse types of biomass energies in other countries which have applied non-market valuation methods. In the United States, Borchers et al. [2] analyzed consumer preferences and estimated the WTP for voluntary participation in green energy electricity programs by designing a CE. Hite et al. [7] investigated whether consumers are willing to pay a surcharge for biopower. Solomon and Johnson [8] used the contingent valuation (CV) method to gain greater understanding of the public's valuation of mitigating global climate change through WTP for biomass or cellulosic ethanol. Susaeta et al. [4] conducted a CE to assess preferences for woody biomass-based electricity. Soliño et al. [9] applied the CV method to evaluate a program whereby 10% of the electricity produced from fossil fuels would be replaced by electricity generated in biomass power plants in Spain. Soliño [3] and Soliño et al. [5] looked into the WTP for a program that promotes the production of electricity from forest biomass by using a CE.

3. Methodologies

3.1. CE approach

The CE approach can offer a promising opportunity to measure the various economic external benefits of WtE and has its theoretical underpinnings in the random utility model, which is

Table 1
Summary of previous studies addressing the economic benefits of biomass energy.

Countries	Sources	Objects to be valued	Methods	Mean WTP estimates
United States	Borchers et al. [2]	Biomass	CE	• USD 10.59 per household per month
	Hite et al. [7]	Biomass	CV	• USD 5.73 per household per month
	Solomon and Johnson [8]	Biomass ethanol	CV	• USD 0.4 per gallon of gasoline
	Susaeta et al. [4]	Woody biomass	CE	• USD 40.5 per person per month
Spain	Soliño et al. [9]	Biomass	CV	• EUR 38 per household per year
	Soliño [3]	Forest biomass	CE	• EUR 18.69 for a reduction of 7% in CO_2 emissions per household per year • EUR 47.95 for a reduction of 14% in CO_2 emissions per household per year • EUR 77.11 to reduce pressure on non-renewable resources per household per year • EUR -13.29 for a reduction in the risk of fires by 25% per household per year • EUR 76.77 for a reduction in the risk of fires by half per household per year • EUR -34.49 for a reduction in the risk of fires by 75% per household per year • EUR 10.37 for the creation of approximately 3000 jobs in rural areas per household per year • EUR 7.33 for the creation of approximately 6000 jobs in rural areas per household per year
	Soliño et al. [5]	Forest biomass	CE	• EUR 50.92 for a reduction of 14% in CO_2 emissions per household per year • EUR 73.09 for a reduction in the risk of fires by half per household per year

Note: CV and CE indicate contingent valuation and choice experiment, respectively.

consistent with economic theory. CE has been employed increasingly in the field of environmental economics to analyze user preferences for environmental resources and to estimate the value of non-market goods and services [4,10–13].

The CE offers a number of advantages. Above all, it is easier to estimate the value of each attribute concerning a target good than using other valuation methods. This is useful because many policies are more concerned with changing attribute levels than losing or gaining the target good as a whole. The CE allows respondents to evaluate systematically trade-offs among multiple attributes. This trade-off process may encourage respondents to facilitate consistency checks on response patterns through introspection. In addition, as the CE does not directly seek the WTP from respondents, it reduces the number of protest responses, especially those involving tax increases or the willingness to accept degradation in return for payment. The CE also increases the amount of information obtained from each respondent, thus reducing the required size of the sample and lowering the cost of the survey.

3.2. *Objects to be valued and attributes*

This study assumes various hypothetical policies which consist of multiple attributes and estimates the external benefits of WtE by assessing these hypothetical policies. To identify the important attributes of the effects of WtE, we selected a preliminary set of attributes derived from extensive literature reviews [3,14]. We then reviewed and revised these through extensive interviews with policy analysts, researchers and professors. Moreover, we used a focus group to discuss participants' understanding of and reaction to the attributes and levels and to refine them. A focus group interview was conducted with 10 participants. This focus group's input helped us to identify the most important and meaningful attributes. Lastly, the final attributes were decided through five criteria outlined below.

First, attributes should be independent or similar to independent of one another. Second, the number of attributes should be small, ideally not more than six, in that trade-offs become difficult to understand and display to respondents in a comprehensible form if there are too many attributes [15]. Third, attributes should be describable by combining simple explanations and visual instruments such as photographs, charts and pictures. Fourth, attributes should be scientifically meaningful and any important fact should not be omitted. Fifth, attributes should be meaningful to people and related to their reasons for estimating the external benefits of WtE. Using these five screening criteria, we identified the four attributes of WtE impacts, such as the improvement of energy security, the reduction of GHG emissions, job creation, and the extension of landfill life expectancy. Table 2 shows five attributes, including the price attribute, and how each level of attributes was defined.

3.3. *The choice sets*

In designing a CE, it is important to define the attribute space (including the attributes and the range) with care, such that it includes the portion that is relevant for the policy questions being asked. Furthermore, CE involves the use of the statistical design theory to construct choice sets that yield coefficient estimates that are not confounded by other factors [17]. In this study, we employed the 'orthogonal main effects design' which is effective in terms of isolating the effects of individual attributes on the choice. The ability to 'design in' this orthogonality is an important advantage over the revealed preference random utility models, in which, in reality, attributes are often found to be highly correlated with one another [10]. The orthogonal main effect design was implemented using the SPSS 12.0 package.

The orthogonal main effect designs allow the estimation of the part-worth for all main effects. Interactions, where the path-worth of a level of one factor depends on the level of another factor, are assumed to be negligible. These designs are attractive to researchers because they are usually quite small in size even when the number of the attributes and their levels is considerably high [16]. Moreover, they can avoid multicollinearity between the attributes and allow a consistent estimation of the effect of all attributes independent of each other. The coefficients estimated using such designs are generally characterized by minimum variance [18].

In the CE questions, there were three alternatives, two of which represented the WtE featuring combinations of attribute levels and specific price levels. The third alternative represented the status quo. There were $4^2 \times 4^2 \times 4^2 \times 4^2 \times 5^2$ possible combinations of attributes and levels to form the choice sets. Since it was impractical to ask respondents to choose from all combinations, we drew a subset of all choice sets to estimate coefficients and drew eight choice sets. They were then randomly divided into two sets of four choices each. Fig. 2 shows an example of a choice set that was actually used in the survey. Each respondent was presented with

Table 2
Attributes and levels of the choice experiment.

Attributes	Descriptions	Levels
Improvement of energy security	Ratio of domestic energy to total energy consumption	Level 1: 4%[a] Level 2: 5% Level 3: 6% Level 4: 8%
Reduction of GHG emissions	Percentage of decrease in the amount of greenhouse gases emission	Level 1: 0%[a] Level 2: 0.5% Level 3: 1.0% Level 4: 2.1%
Job creation	New creation of employment	Level 1: 0[a] Level 2: 10,000 Level 3: 25,000 Level 4: 50,000
Extension of landfill life expectancy	Increase in landfill life expectancy	Level 1: status quo[a] Level 2: doubled Level 3: quadrupled Level 4: septupled
Price	Willingness to pay for expanding waste-to-energy facilities through increasing the monthly electricity bill per household (unit: Korean won)	Level 1: 0[a] Level 2: 1000 Level 3: 3000 Level 4: 6000 Level 5: 10,000

[a] Indicates the current level of each attribute.

	Alternative A	Alternative B	Status quo
Improvement of energy security	6%	8%	4%
Reduction of greenhouse ga s emissions	2.1%	0%	0%
Job creation	50,000 jobs	25,000 jobs	0 jobs
Extension of landfill life expectancy	Doubled	Doubled	Status quo
Monthly surcharge on the electricity bill per household	KRW 1,000	KRW 6,000	KRW 0
Check with √ only the one alternative that you prefer among A, B, or the status quo	□ **A**	□ **B**	□ **Status quo**

Fig. 2. Example of a choice set used in this study.

four choice sets and was asked to choose among the two alternatives and the status quo.

3.4. Questionnaire design and survey method

We prepared a survey questionnaire with the assistance of experts at a polling firm and tested it with a focus group to see how well potential respondents understood the questions. The final version reflected the inputs of the focus group as well as the advice provided by the experts at the polling firm who were assigned to organize the fieldwork.

The final survey questionnaire consists of three parts. The first part aimed to familiarize respondents with the attributes of the WtE being evaluated and to elicit information about their past experiences of these attributes. To enhance respondents' understanding, a color photograph of a process of manufacturing RDF and policy expectations was inserted into this section. The second part contained CE analysis questions that were designed to elicit respondents' WTP for WtE by estimating trade-offs between price and other attributes. The final part elicited socioeconomic information concerning the respondents, such as income, age, and education.

A professional polling firm, Research Prime, Inc., which is located in Seoul, conducted 550 person-to-person interviews, from which we obtained a total of 500 usable observations. The survey was carried out in Seoul, the capital of Korea, where a quarter of the national population resides. Sampling and fieldwork were done by interview experts from the polling firm. The interviews were conducted with randomly selected respondents to maximize the scope for detailed questions and answers.

4. Model

4.1. Multi-nomial logit model

CEs share a common theoretical framework with other valuation approaches. Thus, in this study, the random utility model is used to explain individual choices by specifying functions for the utility that is derived from the available alternatives. This function can be estimated using the multi-nomial logit (MNL) model developed by McFadden [19]. MNL requires that choices satisfy the condition of independence from the irrelevant alternatives (IIA) assumption, which states that for any individual, the ratio of

choice probabilities of any two alternatives is entirely unaffected by the systematic utilities of any other alternatives. According to this framework, the indirect utility function for each respondent i who chooses alternative j in the choice set can be expressed as

$$U_{ij} = V_{ij}(Z_{ij}, S_i) + e_{ij}. \tag{1}$$

The indirect utility function, U_{ij}, can be decomposed into a deterministic part, V_{ij}, and a stochastic part, e_{ij}. The deterministic part is typically specified as a function of the attributes, Z_{ij}, in alternative j that is chosen by respondent i and of respondent i's characteristics, S_i. The stochastic part represents the unobservable influence on individual choice. Furthermore, if $U_{ij} > U_{ik}$ for all $j \neq k$ in the choice set C_i, the probability that respondent i will choose alternative j is given by

$$P_i(j|C_i) = P_i(V_{ij} + e_{ij} > V_{ik} + e_{ik}) = P_i(V_{ij} - V_{ik} > e_{ik} - e_{ij}). \tag{2}$$

In order to deal with this probability, it is necessary to know the distribution of the error term e_{ij}. A typical assumption is that the error terms are independently and identically distributed with an extreme-value (Weibull) distribution, which implies that the probability that any particular alternative j will be chosen as the most preferred can be expressed in terms of the logistic distribution [19]. This probability can be expressed as

$$P_i(j|C_i) = \frac{\exp(V_{ij})}{\sum_{k \in C_i} \exp(V_{ik})}. \tag{3}$$

Each respondent's multi-nomial responses obtained from the questions related to the CE choice sets were interpreted as the choice results from the respondents' utility maximization problem. In this study, each respondent was given four choice sets and asked to choose among three alternatives including the status quo. The choice results for alternative j of respondent i were either 'yes' or 'no'. The log-likelihood function can be written as

$$\ln L = \sum_{i=1}^{N} \sum_{j=1}^{3} (y_{ij} \ln [P_i(j|C_i)]), \tag{4}$$

where y_{ij} is a binary variable (1 when respondent i chooses alternative j among three alternatives and 0 otherwise) and N is the total number of respondents. The parameters of this log-likelihood function are estimated by maximum likelihood estimation.

4.2. Nested logit model

An alternative way of avoiding IIA violations is to allow for correlations among the error terms within different groups or classes of alternatives by estimating a nested logit (NL) model [20]. In a two-level NL model, the probability that respondent i will choose alternative j in class m is represented as

$$P_{ijm} = P_i(j|m) \cdot P_i(m), \tag{5}$$

where $P_i(j|m)$ is the probability that respondent i chooses alternative j, conditional on choosing the outcome class m, and $P_i(m)$ is the probability that respondent i chooses class m.

Assuming that the error term in the respondent's utility functions follows a generalized extreme-value distribution, this probability can be expressed as

$$P_{ijm} = \frac{\exp(V_{jm}/\alpha)\left[\sum_{l=1}^{J_m} \exp(V_{lm}/\alpha)\right]^{(\alpha-1)}}{\sum_{k=1}^{M}\left[\sum_{l=1}^{J_m} \exp(V_{lk}/\alpha)\right]^{\alpha}}. \tag{6}$$

The coefficient, α, is referred to variously as the 'inclusive value coefficient' or the 'dissimilarity parameter'. When $\alpha = 1$, the probability expression in Eq. (6) collapses to the standard MNL probability model, where the IIA property holds among all alternatives. Thus, one way to test for the IIA is to evaluate the null hypothesis, $\alpha = 1$ [21].

4.3. Utility function and MWTP from the model without covariates

The utility function of the model without covariates, with the exception of the error term, e_{ij}, can be expressed as a linear function of an attribute vector, $(Z_1, Z_2, Z_3, Z_4, Z_5)$=(Improvement of energy security, Reduction of GHG emissions, Job creation, Extension of landfill life expectancy, and Price). It includes the alternative-specific constant (ASC), which represents a dummy for the respondent choosing the status quo option among three alternatives.

$$V_{ij} = ASC_i + \beta_1 Z_{1,ij} + \beta_2 Z_{2,ij} + \beta_3 Z_{3,ij} + \beta_4 Z_{4,ij} + \beta_5 Z_{5,ij} \tag{7}$$

where β's are the parameters to be estimated for each attribute that influences the respondent's utility. If we calculate the marginal WTP (MWTP) from the status quo level of each attribute and assume that all the other variables remain constant, we can obtain the following MWTP estimates by totally differentiating Eq. (7) and omitting i for brevity:

$$\begin{aligned} \text{MWTP}_{Z_1} &= -(\partial V/\partial Z_1)/(\partial V/\partial Z_5) = -\beta_1/\beta_5 \\ \text{MWTP}_{Z_2} &= -(\partial V/\partial Z_2)/(\partial V/\partial Z_5) = -\beta_2/\beta_5 \\ \text{MWTP}_{Z_3} &= -(\partial V/\partial Z_3)/(\partial V/\partial Z_5) = -\beta_3/\beta_5 \\ \text{MWTP}_{Z_4} &= -(\partial V/\partial Z_4)/(\partial V/\partial Z_5) = -\beta_4/\beta_5 \end{aligned} \tag{8}$$

The MWTPs of each attribute represent the marginal rate of substitution between the price and each attribute.

4.4. Model with covariates

In order to explain preference heterogeneity and WTP variations among individuals, it is useful to use alternative model specifications where some individual-specific variables (socioeconomic, attitudinal, and past experience) are taken into account. Gordon et al. [22] presented the idea of making the individual-specific variables interact with ASC terms in the utility function. We chose to interact the four individual-specific variables with ASC. This can be formulated using the following utility function:

$$\begin{aligned} V_{ij} = {} & \text{ASC}_i + \beta_1 Z_{1,ij} + \beta_2 Z_{2,ij} + \beta_3 Z_{3,ij} + \beta_4 Z_{4,ij} + \beta_5 Z_{5,ij} + \beta_6 \text{ASC}_i \cdot \text{Income}_i \\ & + \beta_7 \text{ASC}_i \cdot \text{Age}_i + \beta_8 \text{ASC}_i \cdot \text{Education}_i + \beta_9 \text{ASC}_i \cdot \text{Gender}_i \end{aligned} \tag{9}$$

where β_1–β_5 are the parameters to be estimated for each attribute that influences respondents' utilities and the range from β_6 to β_9 represents the parameters to be estimated for individual-specific variables multiplied by ASC_i.

5. Results and discussions

5.1. Estimation results of the models

A total of 550 person-to-person interviews were conducted in June 2013. For this study, 500 were valid for further examination, resulting in a total of 2000 (500×4) observations. The estimation results of MNL and NL models are presented in Table 3 and they do not differ significantly. The coefficients on all the attributes in MNL model are statistically significant at the 1% level. The coefficient estimates for all the variables except for Extension of landfill life expectancy in NL model are also statistically significant at the 1% level. Moreover, their signs are consistent with our expectation. For instance, the coefficients for 'Improvement of energy security', 'Reduction of GHG emissions', 'Job creation', and 'Extension of landfill life expectancy' are all positive. This means that as the level

Table 3
Estimation results of the model.

Variables[a]	Multi-nomial logit coefficient estimates[c]		Nested logit coefficient estimates[c]	
ASC[b]	−0.354[#]	(−3.21)	−0.495[#]	(−5.17)
Improvement of energy security	0.092[#]	(4.19)	0.073[#]	(4.20)
Reduction of GHG emissions	0.380[#]	(7.34)	0.296[#]	(5.70)
Job creation	0.132[#]	(6.59)	0.101[#]	(5.37)
Extension of landfill life expectancy	0.040[#]	(2.77)	0.015	(1.23)
Price	−0.230[#]	(−17.59)	−0.168[#]	(−6.66)
α			0.668[#]	(6.30)
Number of observations	2000			
Log-likelihood	−1938.74		−1934.81	
Wald statistic[d] (p-value)	398.91[#]	(0.000)	277.27[#]	(0.000)

Notes: [c] [#]indicates statistical significance at the 1% level and t-values are reported in parentheses beside the estimates.

[a] The variables are defined in Table 2.

[b] ASC refers to alternative-specific constant, which represents a dummy for the respondent choosing the status quo.

[d] The null hypothesis is that all the parameters are zero and the corresponding p-values are reported in parentheses beside the statistics.

of these attributes increases, the probability of choosing alternatives other than the status quo increases. In contrast, the coefficient for the Price attribute is negative and statistically significant. The higher the price, the lower the probability that respondent i will select the alternative. Using the Wald statistic, estimated equations are statistically significant at the 1% level.

5.2. Specification tests

To test whether the IIA property holds, a Wald test and a likelihood ratio test were carried out. Both the test statistics follow asymptotically a chi-square distribution with one degree of freedom under the null hypothesis that there is no difference between the value of the likelihood function with the unconstrained value and the value of the likelihood function for the constrained estimate, that is, $\alpha=1$. The Wald test statistic is calculated to be 9.79, which is enough to reject the null hypothesis at the 1% level, given that $\chi^2_{0.01}(1)=6.64$. The likelihood ratio statistic of 7.87 exceeds the critical value at the 1% level. Thus, the null hypothesis of $\alpha=1$ can also be rejected. It appears clear from the test results that the IIA assumption for MNL is rejected. Therefore, the NL model is appropriate for the estimation of this data. From now on, we proceed with just the results for the NL model.

5.3. Estimation results of the model with covariates

One can estimate the model with covariates, such as socioeconomic variables. The definitions and sample statistics of the covariates used in this study are presented in Table 4. The mean monthly household income of the sample in this study was KRW 4.75 million (USD 4173). The mean age of the sample was 45.77 years and the mean level of education in years was 14.31. The mean of gender was 0.53, which means 53% of the sample was male. The estimation results of the model with covariates are shown in Table 5. All the estimated coefficients for the covariates are not statistically significant at the 5% level. The estimated coefficients for Income and Education are statistically significant at the 5% and 10% levels, respectively. However, those for Age and Gender are not.

5.4. MWTP estimates of each attribute

The estimation results of the MWTP are contained in Table 6. In the model, the MWTP for the improvement of energy security is calculated to be KRW 437 (USD 0.4) per household. Next, the residents' MWTP for the reduction of GHG emissions is KRW 1763 (USD 1.5) per

Table 4
Definitions and sample statistics of variables in the model.

Variables	Definitions	Mean	Standard deviation
Income	The household's monthly income (10,000 Korean won [a])	475.47 (USD 4172.62)	268.98 (USD 2360.51)
Age	The respondent's age	45.77	9.31
Education	The respondent's education level in years	14.31	2.54
Gender	The respondent's gender (0=female; 1=male)	0.53	0.50

[a] At the time of the survey, USD 1.0 was approximately equal to 1139 Korean won.

Table 5
Estimation results of the nested logit model with covariates.

Variables[a]	Coefficient estimates[c]	
ASC[b]	0.597	(1.29)
Improvement of energy security	0.074[#]	(4.21)
Reduction of GHG emissions	0.298[#]	(5.70)
Job creation	0.100[#]	(5.35)
Extension of landfill life expectancy	0.015	(1.21)
Price	−0.167[#]	(−6.62)
Income	−0.045*	(−2.19)
Age	−0.001	(−1.28)
Education	−0.038	(−1.79)
Gender	0.011	(0.11)
α	0.665[#]	(6.27)
Number of observations	2000	
Log-likelihood	−1928.75	

Notes: [c] *and [#] indicate statistical significance at the 5% and 1% levels, respectively, and t-values are reported in parentheses beside the estimates.

[a] The variables are defined in Tables 2 and 4.

[b] ASC refers to alternative-specific constant, which represents a dummy for the respondent choosing the status quo.

household. The MWTP for job creation and the extension of landfill life expectancy is KRW 598 (USD 0.5) and KRW 89 (USD 0.1), respectively, per household. The MWTPs for the three attributes (Improvement of energy security, Reduction of GHG emissions, and Job creation) are statistically significant at the 1% level. The Seoul residents put the highest value on the Reduction of GHG emissions. However, people are less sensitive to the Extension of landfill life expectancy.

Moreover, we construct confidence intervals for the point estimate of the MWTP for each attribute in order to allow for uncertainty, rather than only reporting the point estimate [23]. The Monte Carlo simulation technique suggested by Krinsky and Robb [24] is used to generate 95% confidence intervals for the MWTP, which are presented in Table 6.

5.5. Evaluation of the scenarios in the WtE program

One of the strengths of CEs is that the estimated coefficients of the attributes may be used to estimate the WTP under various scenarios in which the attributes can be combined. In this paper, four different WtE programs are considered. They include the improvement of energy security, the reduction of GHG emissions, job creation, and the extension of landfill life expectancy. Table 7 presents the results for the external benefit to households for each scenario. For example, Scenario A describes a 6% improvement in energy security, 2.1% reduction in GHG emissions, the creation of 50,000 jobs, and double the landfill life expectancy. The monthly

Table 6
Marginal willingness to pay (MWTP) estimates and their confidence intervals.

Attributes	MWTP per month per household		
	Estimates	*t*-Values	95% confidence intervals
Improvement of energy security (unit: 1%p)	KRW 437[#] (USD 0.4)	4.45	KRW 252 to 652 (USD 0.2 to 0.6)
Reduction of GHG emissions (unit: 1%p)	KRW 1763[#] (USD 1.5)	6.09	KRW 1246 to 2435 (USD 1.1 to 2.1)
Job creation (unit: 10,000)	KRW 598[#] (USD 0.5)	6.99	KRW 434 to 785 (USD 0.4 to 0.7)
Extension of landfill life expectancy (unit: times)	KRW 89 (USD 0.1)	1.33	KRW −59 to 212 (USD −0.1 to 0.2)

[#] Indicates statistical significance at the 1% level.

Table 7
Scenarios of the waste-to-energy program.

Attributes	Scenario A	Scenario B	Scenario C	Scenario D
Improvement of energy security	6%	8%	8%	4%
Reduction of GHG emissions	2.1%	1.0%	0.5%	0.5%
Job creation	50,000	25,000	10,000	50,000
Extension of landfill life expectancy	Doubled	Doubled	Quadrupled	Septupled
Monthly external benefits per household	KRW 7744 (USD 6.8)	KRW 5184 (USD 4.5)	KRW 3584 (USD 3.1)	KRW 4495 (USD 3.9)

external benefits for Scenarios A, B, C, and D are estimated to be approximately KRW 7744 (USD 6.8), KRW 5184 (USD 4.5), KRW 3584 (USD 3.1), and KRW 4495 (USD 3.9) per household, respectively. The scenarios provide important insights into WtE policy and will certainly be a useful tool for experts and decision-makers.

6. Concluding remarks

This study was motivated by the need for information to help policy-makers take appropriate actions to improve WtE in Korea. The study aimed to measure the external benefits of WtE by applying a CE to four attributes or types of benefits, such as the improvement of energy security, the reduction of GHG emissions, job creation, and the extension of landfill life expectancy. The results suggest that people are willing to pay a premium for electricity to acquire the external benefits of WtE. The MNL model widely employed in dealing with CE data requires a restrictive assumption of IIA. Thus, as an alternative to the MNL model, we utilized an NL model here. Two specification tests indicate that the NL model outperformed the MNL model. The estimation results for the NL model show that the MWTPs for a 1% increase in energy security, a 1% reduction in GHG emissions, the creation of 10,000 jobs, and the doubling of landfill life expectancy caused by expanding WtE facilities were estimated to be KRW 437 (USD 4.5), 1763 (1.5), 598 (0.5), and 89 (0.1) per household per month. These findings can provide policy-makers with useful information for evaluating and planning WtE policies and projects.

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